Mixed-Reality Exercise Effects on Participation of Individuals with Spinal Cord Injuries and Developmental Disabilities: A Pilot Study

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Objective: The purpose of this pilot study was to investigate the effectiveness of a mixed-reality (MR) exercise environment on engagement and enjoyment levels of individuals with spinal cord injury (SCI) and intellectual and developmental disabilities (IDD). **Methods:** Six people participated in this cross-sectional, observational pilot study involving one MR exercise trial. The augmented reality environment was based on a first-person perspective video of a scenic biking/walking trail in Colorado. Males and females (mean age, 43.3 ± 13.7 years) were recruited from a research database for their participation in previous clinical studies. Of the 6 participants, 2 had SCI, 2 had IDD, and 2 were without disability. The primary outcome measurement of this pilot study was the self-reported engagement and enjoyment level of each participant after the exercise trial. **Results:** All participants reported increased levels of engagement, enjoyment, and immersion involving the MR exercise environment as well as positive feedback recommending this type of exercise approach to peers with similar disabilities. All the participants reported higher than normal levels of enjoyment and 66.7% reported higher than normal levels of being on a real trail. **Conclusion:** Participants' feedback suggested that the MR environment could be entertaining, motivating, and engaging for users with disabilities, resulting in a foundation for further development of this technology for use in individuals with cognitive and physical disabilities. **Key words:** *developmental disability, exercise, mixed-reality, rehabilitation, spinal cord injury*

The positive physical and psychological effects that physical exercise produces have been well-documented through extensive research over many decades of investigation; this has contributed to the general acceptance of the belief that regular physical activity results in increased longevity.[1] Many studies have shown that adherence to physical exercise helps to maintain healthy weight[2]; reduce the risk of developing numerous diseases[3]; improve cognitive function[4-6]; reduce and even prevent symptoms of depression,[7] anxiety,[7] and other mood disorders[6]; and improve overall quality of life.[8] One study supports that people with disabilities have the same affirmative response to physical exercise as people without disabilities.[9] However, people with disabilities have unique challenges that make their adherence to and participation in physical exercise difficult.[10] Some of the most common challenges are architectural barriers at community fitness facilities including an absence of elevators, grab bars, and the delayed repairs of these and other accommodations.[10] It has been reported that another significant barrier is the attitude of staff members at fitness facilities who are interacting with people with disabilities.[10] Rolfe et al[10] reported the in-depth descriptions provided by females with disabilities that their motivation was hindered and their adherence to exercise was lost when fitness facility staff members failed to match the exercise to their abilities. On the contrary, when staff members were willing to learn about these clients' abilities and adapt exercise programs to match those abilities, their health outcomes were achieved possibly due to their increased levels of motivation and adherence. Rolfe's study is important in that it investigated the barriers that women with disabilities encounter in fitness facilities, which can be translated universally to both men and women with physical and cognitive disabilities.

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Kehn and colleagues[11] investigated the barriers and facilitators to exercise participation in people with spinal cord injury (SCI). They reported that people with SCI find it more difficult to adhere to an exercise program due to physical/environmental barriers and to motivational/psychological barriers. Because of the barriers that people with disabilities experience, there needs to be a different approach for engaging people with physical or cognitive disabilities in physical activity to increase their health, function, and quality of life.

Augmented environments, such as virtual reality (VR) and mixed reality (MR), are innovative technologies for rehabilitation.[12-14] MR allows interactions with the real and simulated environments through 3-dimensional images reproduced on a screen.[15] In contrast, VR requires head-mounted displays (HMD), tracking systems, earphones, gesture-sensing gloves, and haptic feedback devices to create a full immersion in the simulated world.[13] Augmented environments share the advantages of precise control, such as the systematic human testing and systematic training environments. Some rehabilitation researchers feel that MR is friendlier, more adjustable, and more adaptable than full immersion systems.[15] MR in physical rehabilitation can be designed to be interactive, engaging, and enjoyable and at the same time provide physical movement and training to achieve higher levels of functioning.[14-19]

VR is an evolving technology that has been applied to rehabilitation in the areas of motor and cognitive training for persons with and without disabilities.[12,13,18] Some advantages of VR are (a) its safety, with minimal side effects and a decrease in the risks encountered in the real environment; (b) the objectivity of the data collected for evaluation and treatment; and (c) computer-generated stimuli convenience, such as the amount, speed, and order of the therapeutic stimulus.[12,15,18] Additional benefits for rehabilitation include the opportunity for experiential and active learning, the ability to objectively measure behavior in challenging but safe and ecologically valid environments, and the ability to maintain control over stimulus delivery and measurement to individualize treatment needs.[20,21] These benefits are achievable due to the unique property of immersion and interaction based on the subject/object stimulus feedback association that is simulated and enriched in a therapeutic environment created by a computerized system.[22] More specifically, VR has become an effective approach for rehabilitation and adherence to physical exercise in people with SCI[22,23] and intellectual and developmental disabilities (IDD)[20,21] as compared to conventional training programs that are not usually sufficient for motivating persons with disabilities. Lotan et al[20] reported the use of VR as a means to improve physical fitness in individuals with IDD by increasing their motivation and adherence to their rehabilitation program. Many other benefits of incorporating VR exercise environments into rehabilitation programs have been reported.[20-22] Carlozzi et al[22] showed benefits of using VR-based rehabilitation therapy for improvements in upper arm movement and balance in those with SCI.

This evidence can lead to the incorporation of VR environments in community fitness facilities and home-based exercise to increase the levels of motivation and adherence to a physical exercise routine in people with SCI, IDD, and many other disabilities. Therefore, we developed a technology based on a novel MR system that aims to provide safe and enjoyable exercise environments for individuals with SCI and IDD. With a cross-sectional and observational pilot feasibility study design, we evaluated the MR exercise system by obtaining data about the users' experience of the system and their adherence to and enjoyment of performing endurance exercises on the MR system.

Methods

Participants

Six participants (3 females and 3 males) were recruited from the Assistive Technology Partners clinic to participate in this cross-sectional pilot study. Among the participants, 2 had SCI, 2 had IDD, and 2 did not have disabilities. The age range of the participants was 23 to 57 years old, and the mean age was 43.3 years (SD = 13.7). Exclusion criteria for participants included a history of cardiovascular disease, chronic obstructive pulmonary disease, uncontrolled diabetes mellitus, and other ailments of the musculoskeletal and pulmonary systems. People with SCI who could not remain mobile independently in their wheelchairs were also excluded from this study. This study was approved by the Colorado Multiple Institutional Review Board (COMIRB #05-0571), and informed consent was obtained from all research participants.

Augmented reality environment and exercise setup

For the purpose of this pilot study, the system was designed to encompass and expose the participants to the real environment and the augmented environment, defined as MR. Participants were asked to exercise on endurance training equipment and at the same time interact and respond to an augmented environment exposed on a large screen. The exercise equipment that was used consisted of a treadmill, recumbent and upright exercise bicycles, and an upper-body arm ergometer. Training was conducted with each participant on the use of each device. Participants were also instructed about the benefits of exercise, effective exercise intensity, and heart rate monitoring by an exercise physiologist. The augmented reality environment was played on 3 large, flat-panel, 40-in. television monitors arranged in a U-shape (cave) in which the participants exercised. A first-person perspective video recording of traveling forward along a Colorado biking/walking trail was played on the television monitors during the augmented reality exercise session. The feedback system was engineered and incorporated into the exercise equipment and augmented reality environment so that if a participant's speed of movement decreased so did the speed of the video, and vice versa.

Experimental protocol

The experimental protocol was based on a 1-hour session. Participants were asked to come to an exercise lab at a disability and assistive technology community-based clinic. During each individual exercise session, a specialized physical therapist (PT) was present. This PT also conducted the individual health and physical evaluations. Each participant's level of endurance was evaluated and the intensity of the exercise sessions was accommodated to the participants' abilities and the equipment used. The time range for the MR exercise sessions was 17 to 35 minutes with a mean of 26.17 minutes (*SD* = 6.79). Three participants exercised using a treadmill, 2 used recumbent and upright bicycles, and 1 used an upper-body arm ergometer. Following the MR exercise session, participants were given an 8-question survey in which they ranked their experience on a Likert scale from 1 to 7 (**Table 1**).

Analysis

The method used to collect and analyze data in this study relied on the qualitative clinical observations during and after each participant's exercise session and his or her self-reported experiences. The instrument used to collect the qualitative data from each user's experience was adapted from Witmer and Singer's Presence Questionnaire.[24] Based on the nature of this pilot study, we selected items from the questionnaire that were most applicable to the level of MR exposure that participants experienced during one session. Therefore, only 8 items from the Presence Questionnaire[24] were selected to evaluate users' experience of the technology (**Table 1**). We thought that reducing the participants' burden in responding to unnecessary questions would increase their ability to provide an appropriate evaluation of their experience. Participants were asked to rank their experience on a Likert scale from 1 to 7 (ie, 1 = *least*, 7 = *most*). The qualitative data were transcribed and categorized based on user experience (ie, dislike or like). The questionnaire data were analyzed by descriptive statistics in which proportion analysis (percentage) was used to quantify user experience. The data were analyzed using IBM SPSS Statistics 17.0 (IBM Corp., Armonk, NY).

Results

Clinical qualitative observations

During and after the exercise sessions, participants were asked to express their personal experience with the technology and study setup.

Table 1. Adapted presence questionnaire

	Percent
1. I had a sense of being on a real trail. (1 [at no time] – 7 [all of the time])	
4 – no difference	50.0
5 – almost all of the time	16.7
7 – all of the time	33.3
2. During the time of the experience, I had a stronger sense of… (1 [being in a lab] – 7 [being on a trail])	
4 – no difference	33.3
5 – almost on a real trail	16.7
6 – mostly on a real trail	16.7
7 – on a real trail	33.3
3. The experience was enjoyable. (1 [not at all] – 7 [extremely])	
5 – most of the time	16.7
6 – almost all of the time	50.0
7 – all of the time	33.3
4. How often would you exercise using this technology? (1 [rarely] – 7 [every day])	
5 – most days of the week	33.3
6 – almost all days of the week	33.3
7 – all days of the week	33.3
5. Given the choice between the MR setup and watching television or listen to music while exercising, would you use the MR setup over watching television or listening to music? (1 [rather watch TV/listen to music] – 7 [use equipment])	
1 – rather watch TV/listen to music	16.7
4 – no preference	33.3
5 – almost always use the equipment	33.3
6 – mostly use the equipment	16.7
6. How often did the technology give you a sense of immersion? (1 [at no time] – 7 [all of the time])	
3 – almost none of the time	16.7
5 – almost all of the time	33.3
6 – most of the time	33.3
7 – all of the time	16.7
7. Would you recommend this exercise setup to others? (1 [would not] – 7 [would recommend to everyone])	
5 – would recommend to almost everyone	33.3
6 – would recommend to mostly everyone	16.7
7 – would recommend to everyone	50.0
8. The technology made the exercise experience seem quicker than usual. (1 [felt the same] – 7 [felt much quicker])	
5 – felt slightly quicker than usual	33.3
6 – felt mostly quicker than usual	16.7
7 – felt quicker than usual	50.0

Note: MR = mixed reality.

Participant S6 responded that "it was difficult to start and stop the exercise machines because [his] hands were tied on." His recommendation was to develop and implement footplate and handgrip adaptors into the upper-body arm ergometer to provide a more complete exercise experience for persons with SCI. A recommendation from participant S4 was to take individual entertainment preferences into account rather than provide one virtual biking trail. All participants stated that they would be much more likely to adhere to an exercise schedule in an MR environment. Participant S1 stated that exercise was important to her because "it kept [her] heart going" and that her sister "wanted [her] to lose weight." Participant S1 also noted that on several occasions she frightened herself by adjusting the treadmill to speeds that were too fast for her to maintain and she required assistance in stopping the treadmill. She stated that she "preferred to use the stationary bicycle" after

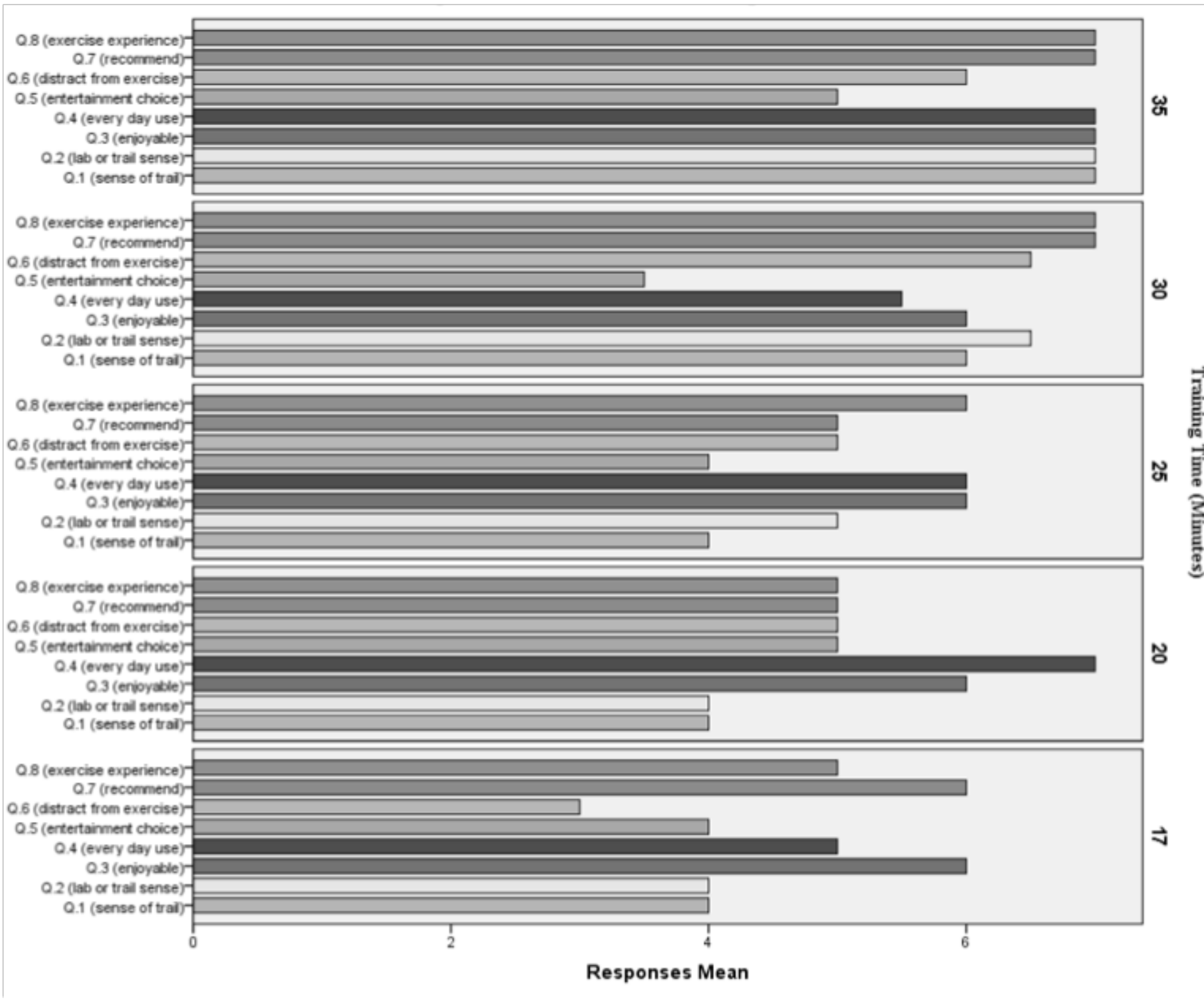

Figure 1. Presence levels and training time.

the last incident of a speed too fast on the treadmill. Participant S6 stated that exercise improved his mood and that the MR exercise environment provided an easier way for him to obtain happiness than traditional modes of exercise; he "liked the routine and stress relief of regular exercise." Additionally, participant S6 stated that he "did not believe in having lower expectations for people with disabilities" and felt that "[his] physical exertion should be the same as that of a person without a disability." Participant S6 also stated that "[he] enjoys exercising but [did not] belong to a gym because [he] prefers to exercise at home" and that "driving to the gym and back takes time out of [his] already busy day."

Participants' experience of presence

The results from the Adapted Presence Questionnaire (**Table 1**) indicate that most of the participants showed a higher level of enjoyment and immersion in the augmented reality exercise environment than during exercise without it. The questionnaire responses indicate that each participant would be more than likely to recommend an augmented reality exercise

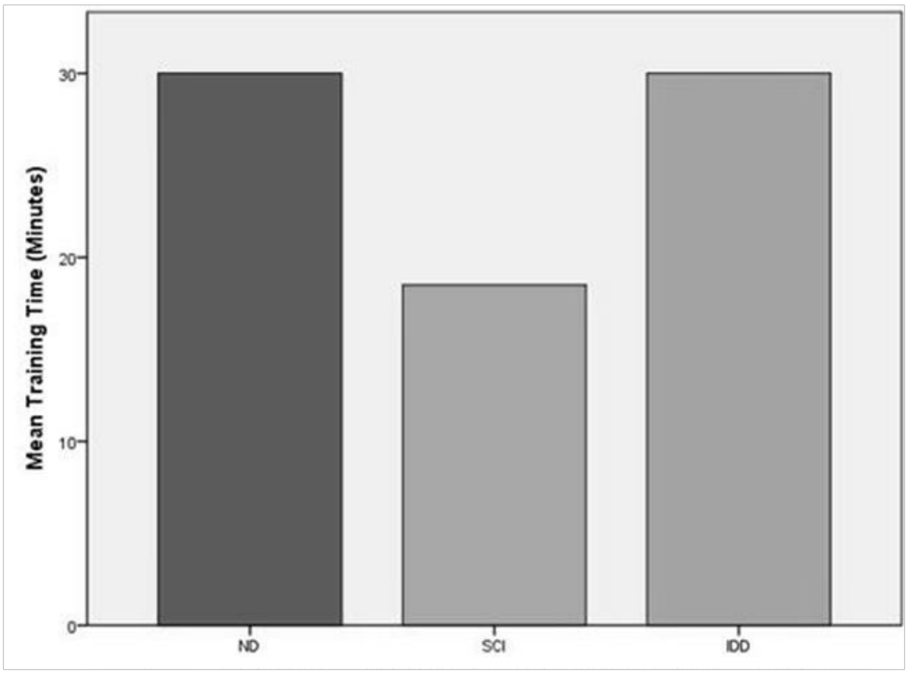

Figure 2. Training tolerance of participants according to type of disability. ND = nondisabled; SCI = spinal cord injury; IDD = intellectual and developmental disabilities.

environment to others (with and without disabilities). Analysis also supported the finding that the participants who tolerated the session the longest also reported higher levels of presence and enjoyment (**Figure 1**). Nondisabled and IDD individuals showed similar tolerance levels during the sessions for training (**Figure 2**).

Discussion

Despite growing evidence for the use of augmented environment technology in many different aspects of humans' lives, there is a lack of investigation in the feasibility of using MR environments to engage people with physical and cognitive disabilities in participation and adherence to therapeutic physical exercise. The health risks faced by individuals with physical and cognitive disabilities are many and serious. It is generally accepted that sedentary lifestyles result in detrimental health problems; therefore, there is a need for newer and more effective approaches to encourage sedentary individuals to engage in and maintain exercise habits. The daily barriers and limitations that persons with SCI and IDD face often result in a sedentary lifestyle. The removal or modification of these barriers elicits higher levels of adherence and enjoyment during physical exercise for those with SCI and IDD when MR is incorporated into their exercise routines. The use of MR to help increase levels of enjoyment and engagement in rehabilitation is a promising area of investigation.[25-27]

The results of this pilot study show the need to advance this study into a more complex and comprehensive trial that will include different technology perspectives and MR approaches, especially for persons with SCI.[27] Additionally, the results of this study support the finding that individuals with SCI have greater difficulty in sustaining prolonged exercise practices, possibly due to the physical barriers associated with SCI. It is essential to provide participants with accommodations to allow them to perform as independently as possible while using exercise equipment. There is a greater need to discover and test new technologies combined with exercise rehabilitation approaches for individuals with

SCI than for individuals without. This pilot study provides preliminary evidence that MR rehabilitation is beneficial to those with physical and cognitive disability. Future studies should investigate the effectiveness of MR exercise therapy over longer periods of time (eg, a MR exercise regimen over the course of 6-8 weeks, with exercise sessions occurring 2-3 times per week). There is the potential that the novelty of the MR exercise system may promote participation, but that adherence may decrease when the novelty wears off. This possibility needs to be investigated by examining this intervention over an extended period of time.

The physical limitations to exercise for individuals with SCI seem to diminish when an immersive environment is introduced. A study conducted by Zimmerli and colleagues [25] utilized the Unity3D game engine (Unity Technologies, San Francisco, CA) to develop different VR exercises that were projected onto screens in front of participants during their exercise sessions. This study supports that practical approaches to VR exercise rehabilitation are becoming affordable and home-based through the potential use of motion-sensing input devices like Microsoft's Xbox 360 Kinect (Microsoft, Redmond, WA) and Nintendo's Wii (Nintendo, Kyoto, Japan), which are capable of detecting movement in 3 dimensions. This is important as the technology used in our study is more than likely too expensive for commercial production and public use. As technology advances, future studies of VR and MR exercise therapies will use more sophisticated technologies to investigate the effectiveness of this modality in the field of rehabilitation. Advancing technology will most likely augment the physical experience further by incorporating different sensory stimuli into the exercise environment. These can include technologies to produce auditory, olfactory, and tactile stimuli.

The small sample size might limit our ability to generalize the findings of this study, as 6 participants may not be representative of the potential user's variability. The lack of treatment design is also a limitation in the investigation of the user experience of MR. Another limitation was the absence of a control group. With a control design, measurements of physical analysis would have provided a means for determining whether an individual was not only enjoying physical exercise, but also whether healthy outcomes were occurring more frequently as opposed to during exercise in the traditional manner without an augmented MR environment. The short treatment period of a one-time exercise session for each participant was also a limitation. Ideally, a longer intervention with additional observations of variance between exercise sessions and compliance is needed.

Although this pilot study presents several limitations such as small sample size, lack of a control group, and no inclusion of a treatment design, the results are promising and support the need to further evaluate applications of MR technologies in rehabilitation settings as well as to support persons with physical and cognitive disabilities in adopting healthy lifestyles. It is also important to consider the community- and home-based translation that this research can provide to patients with complex disabilities, as some patients may be uncomfortable exercising in a clinical environment.

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